TESTING OF THE IRT-4M TYPE FA WITH LEU UO_2-Al FUEL IN WWR-CM REACTOR

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ABSTRACT

Now in the WWR-CM reactor (Tashkent) the IRT-3M type Fuel Assemblies (FA) with UO_2-Al fuel of 36% enrichment are used. Density of uranium in the Fuel Elements (FE) meats – 2.5 g/cm^3. Thickness of meats – 0.5 mm. The WWR-CM reactor conversion on use of these FA was begun in August, 1998 and was completed in February, 1999. According to the Russian RERTR program in the WWR-CM reactor the lifetime testing of four IRT-4M type FA (two 8-tube and two 6-tube) with LEU (19.7%) UO_2-Al fuel will be carried out. These FA were fabricated by JSC “Novosibirsk Chemical Concentrates Plant” (NZHK). Uranium density in the FE meats – 3.0 g/cm^3. FE cladding material in two FA is aluminum alloy CAB-1, and in two others – alloy AMr2. Neutronic and thermal-hydraulic calculations in a substantiation of safety of the IRT-4M type FA testing were performed. Results of calculations are presented. The IRT-4M type FA testing will be begun in October, 2000.

INTRODUCTION

The WWR-C research reactor located at the Institute of Nuclear Physics of the AS of Uzbekistan Republic has reached initial criticality in September, 1959 [1].The rated reactor power was 2 MW. Fuel assemblies with fuel elements of the pin type with fuel of 10% enrichment were used in the reactor. In 1971 the Russian Research Centre “Kurchatov Institute” has developed the project of reconstruction of the WWR-C reactor on the basis of use of the IRT-2M type FA with FE of a tubular type and fuel (UAl alloy) of 90% enrichment [2]. The reconstruction of the WWR-C reactor, carried out in 1971, has ensured a possibility of increase of its power with 2 to 10 MW. Since 1979 in the WWR-CM reactor the IRT-3M type FA began to be used. The heat transfer surface of the IRT-3M type FA is twice higher, than of the IRT-2M type FA. In FE of the IRT-3M type FA fuel (UAl alloy) of 90% enrichment also was used [3].

Since March, 1987 till March, 1989 in the WWR-CM reactor the lifetime testing of three the IRT-3M type FA (two 6-tube and one 8-tube) with UO_2-Al fuel of 36% enrichment were carried out. These FA were developed within the framework of the first stage of the Reduced Enrichment for Research and Test Reactors Program in former Soviet Union (1978–1988) [4]. Density of uranium in FE meats of these FA was 2.5 g/cm^3. Thickness of meats – 0.5 mm.

The testing of these FA have passed successfully with achievement of fuel burnup more than 50% [5].
The WWR-CM reactor conversion to use of the IRT-3M type FA with fuel of 36% enrichment was begun in August, 1998. The conversion of the WWR-CM reactor provided consecutive replacement of a part most burnup FA with fuel of 90% enrichment by FA with fuel of 36% enrichment. The core configuration of first mixed loading of the WWR-CM reactor with fuel of 90% and 36% enrichments is shown in Figure 1 [6]. For its formation from the core four FA with average burnup of fuel 56.9, 56.2, 55.5 and 53.9% were unloaded and also four fresh FA with fuel of 36% enrichment were loaded. Since August, 1998 till February, 1999 four mixed loadings of the reactor were formed, with which it has operated 6 cycles.

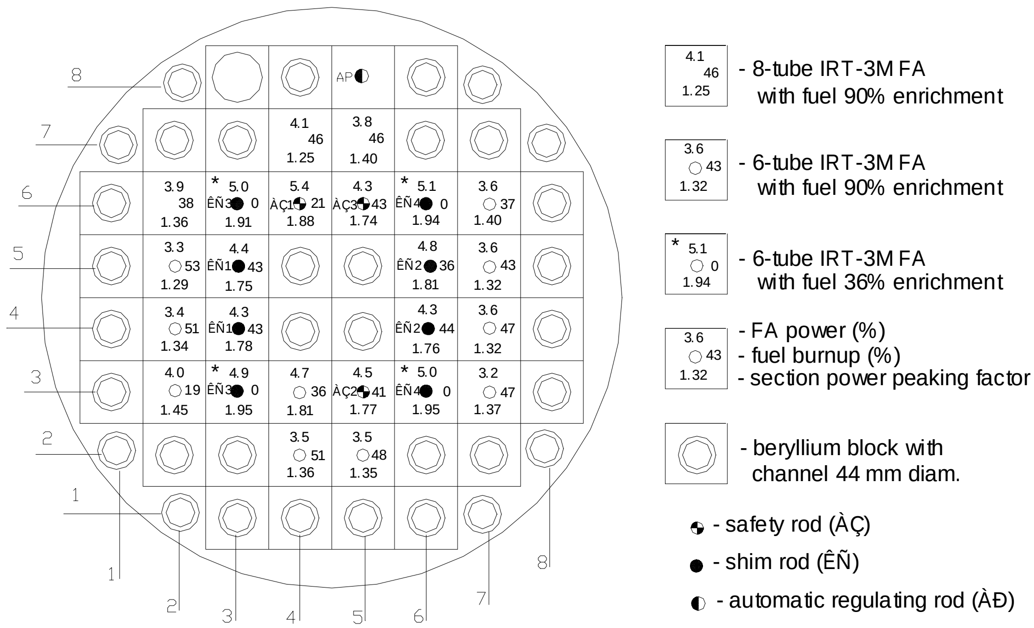


Figure 1. The core configuration of the first mixed loading of the WWR-CM reactor with fuel of 90 and 36% enrichment. (beginning of operating cycle, insertion of KC-3 and KC-4 – 65 cm)

In forming of the fifth loading from the WWR-CM reactor 12 FA with initial 90% enrichment of fuel with burnup 60% and more were unloaded. In fifth reactor loading (no longer mixed) the fuel assembly number in the core came to 16. With fifth loading of the core the reactor has operated 6 cycles. In July, 1999 the compact loading of the WWR-CM reactor was formed (Figure 2). Four FA (from 7-4, 7-5 and 2-4 cells and one fresh) were loaded instead of beryllium blocks (4-4, 4-5, 5-4 and 5-5 cells). In addition to that the reactor excess reactivity has increased on ~3.5% $\Delta k/k$.

In October, 2000 in the WWR-CM reactor the lifetime testing of four IRT-4M type FA with LEU UO_2-Al fuel will be begun. These FA were fabricated by JSC NZHK according to the Russian RERTR. Density of uranium in FE meats of these FA – 3.0 g/cm^3. For a choice of the WWR-CM reactor cells, in which it is necessary to place the IRT-4M type FA, and also for a substantiation of safety of testing them in these cells, neutronic and thermal-hydraulic calculations were performed.

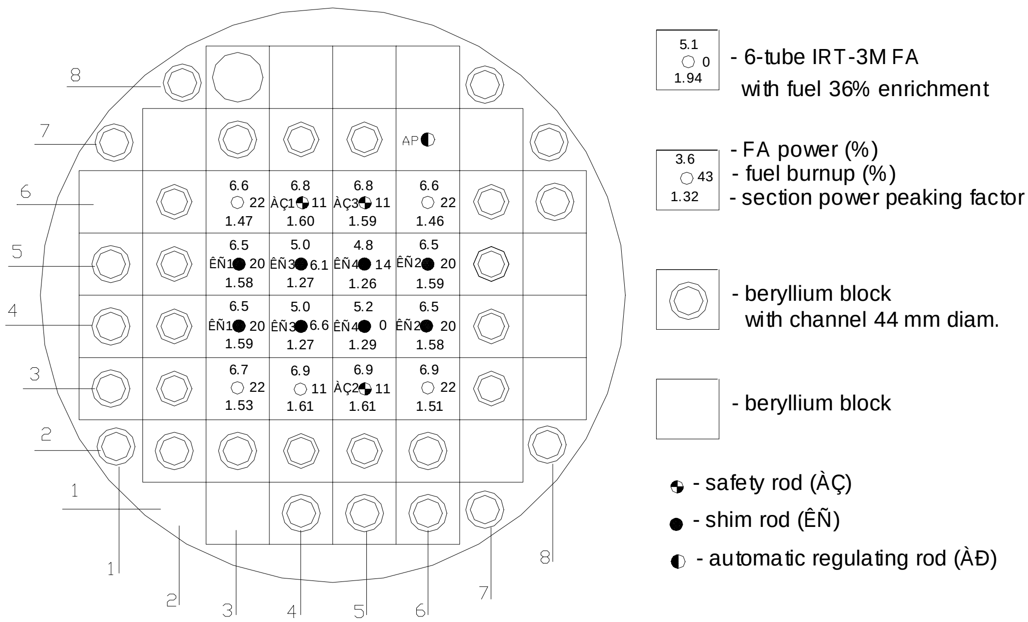
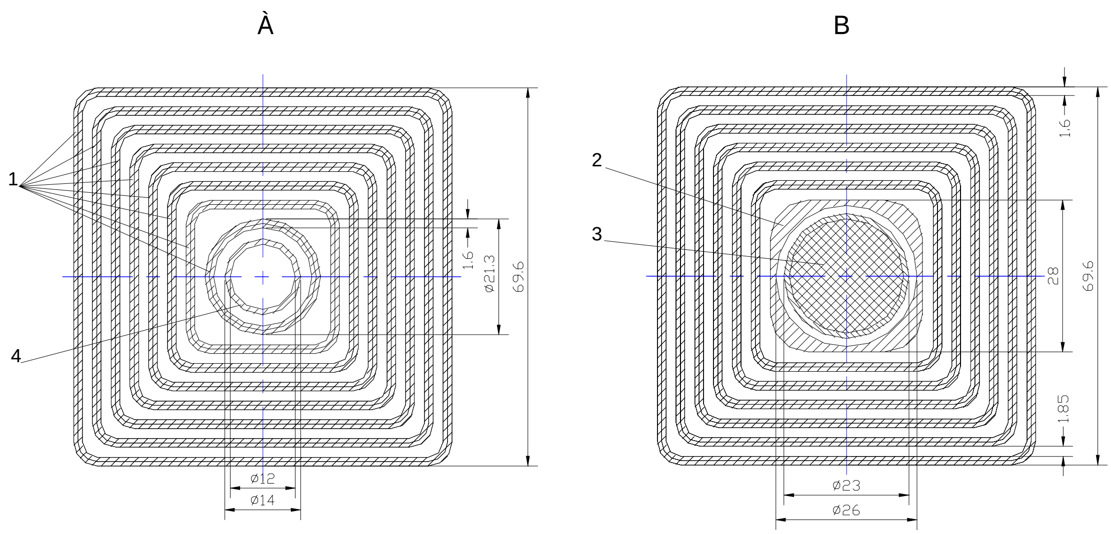


Figure 2. The core configuration of the compact loading of
the WWR-CM reactor with fuel of 36% enrichment (July, 1999)
(beginning of operating cycle, insertion of KC-3 and KC-4 – 65 cm)

THE IRT-4M TYPE FUEL ASSEMBLY

The development of the IRT-4M type FA was performed with the purpose of a possibility of conversion on LEU fuel of research reactors, in which FA of the IRT-2M or IRT-3M type with fuel 90, 80 or 36% enrichment are used, but without change of the fuel composition of FE meats (UO_2-Al), using in Russia. The first variant of the IRT-4M type FA (Figure 3), differing from IRT-3M type FA by FE thickness (1.6 instead of 1.4 mm), meat thickness of FE (0.7 instead of 0.4-0.5 mm) and thickness of gaps between FE (1.85 instead of 2.05 mm), was developed with use of FE with the density of uranium in meats equal 3.85 g/cm^3. The necessity of use in the IRT-4M type FA of FE with such density of uranium in their meats was confirmed also by calculation executed in ANL [7].

FE of two sizes for the IRT-4M type FA (second and third, considering outside) with meats from UO_2-Al with the density of uranium in them 3.85 g/cm^3 were made by JSC NZHK in 1995. The testing of these FE within experimental (combined) FA (the IRT-3M type FA with two FE of IRT-4M type) was begun in May, 1996 in the IR-8 reactor in RRC “Kurchatov Institute” [8].
The testing was interrupted in middle of 1998 in connection with a shutdown of the IR-8 reactor for replacement aluminum heat exchangers of the reactor cooling system operated since 1957. To



the IR-8 reactor shutdown the average burnup of fuel in FE of the IRT-4M type achieved 33-34%, maximum burnup – up to 53%.
Three full size the IRT-4M type FA were fabricated by JSC NZHK in 1996. The testing of these FA in the IR-8 reactor was begun in February, 1997. In connection with cladding failure of some FE in these FA their testing was stopped.

Figure 3. The IRT-4M type FA cross section

A – 8-tube FA B – 6-tube FA

1 – fuel elements; 2 – channel of control rod; 3 - control rod; 4 – central displacement tube

To taking account of results of the IRT-4M type FA testing with the density of uranium in FE meats 3.85 g/cm^3, it was decided to develop the second variant of this type FA with the density of uranium in meats 3.0 g/cm^3. It is obvious, that the use of this variant FA of the IRT-4M type will not allow to keep the cycle length of reactor operation achieved with FA of the IRT-3M type. However for the certain period, before development of FE with fuel on a base of UMo alloy, which will allow to make FE with the density of uranium in the meats ~5.4 g/cm^3 at its thickness of 0.5 mm, it will ensure an opportunity to deliver FA with LEU fuel for the Russian designed research reactors currently operating with HEU fuels.

In 1999 JSC NZHK has fabricated four assembly of the second variant the IRT-4M type FA: two 8-tube and two 6-tube. The basic parameters of these FA are presented in the table 1 [9].

Table 1. The basic parameters of the IRT-4M type FA (second variant)

№ FA	Thickness, mm			Density of uranium in the meat, g/cm^3	Material		Fuel enrich-ment, %	The con-tent of uranium-235, g
	FE	Meat	Clad-ding		Meat	Clad-ding		
19ИМ0499	1.6	0.7	≥0.31	3.0	UO_2-Al	САВ-1	19.7	297.8
!9ИМ0599	-“-	-“-	-“-	-“-	-“-	АМг2	-“-	299.5
19ИМ0699	-“-	-“-	-“-	-“-	-“-	САВ-1	-“-	260.3
19ИМ0799	-“-	-“-	-“-	-“-	-“-	АМг2	-“-	264.6

As it is seen from the table 1, in two FA for claddings of FE the alloy САВ-1 is used. This alloy is applied in FE of the IRT, WWR-M and WWR-TS type FA almost within 40 years. In two others the alloy АМг2 is used.

TECHNIQUE AND CODES OF NEUTRONIC CALCULATIONS

The neutronic calculations of loadings of the WWR-CM reactor are conducted with use of the IRT-2D/PC code [10] and complex TDD-URAN code, which one includes:

- The URAN-D code for a reactor cylindrical cell neutronic calculation which takes into consideration isotopic change under burnup (adapted and upgraded URAN-AM code [11]). The URAN-D code is a module in a system of the reactor calculation, computing on specially developed and tested up techniques the macroconstantes (cross-sections) for cells of the reactor inclusive FA, CPS rods or reflector units, and bringing result in the database.
- The TDD-D code for three-dimensional calculation of a nuclear reactor in two- group (fast group: 0,625 eV<E<10 MeV; thermal group: 0 eV<E<0,625 eV) diffusion approximation (adapted and upgraded TDD-C4 code [12]) with use of the database and unit of fuel burnup calculation in the reactor. The average fuel burnup in each FA and distribution of burnup on the core height are calculated with use of power values of fuel assemblies. In particular, the knowledge of the distribution of fuel burnup in FA on the core height enables more precisely to know quantity of the stayed fuel.
- The automated interface between these codes utilizing the database of neutronic constants.

Results of neutronic calculations were tested up on numerous experimental data. With the purpose of verification of a few-group diffusion theory codes of neutronic calculation of research reactors with the IRT-M type FA (IRT-2D/PC code [10], TDD-C/4 code [12], URAN-AM code [11] and its modifications) for loadings with "fresh" fuel of research reactors SR-0 (Plzen), IRT-1 (Libyan A.J.), IRT-T (Tomsk), IRT-MEPhI (Moscow) and WWR-CM (Tashkent) the calculations of such parameters so relevant for safety of a nuclear reactor, as excess reactivity and reactivity worth CPS rods, are executed. The IRT-2M type FA and IRT-3M type FA with enrichment of fuel 36%, 80% and 90% are used in these reactors. Comparison of results of reference calculations with experimental data demonstrates, that with use IRT-2D/PC, TDD-C/4 and URAN-C codes the excess reactivity can be calculated with accuracy not worse than 0.1

% Δ k/k, and reactivity worth CPS rods–0.15 % Δ k/k [13]. Comparison of results of calculations of the IR-8 research reactor (RRC "KI") with use IRT-2D/PC and URAN-C codes at use in the IRT-3M type FA of fuel enriched up to 90% and 36% with the data of Monte-Carlo calculations by MCNP code demonstrates, that in engineering calculations the excess reactivity of loadings differs approximately on 1.0 % Δ k/k [14].

CHOICE OF CORE CELLS FOR TESTING OF THE IRT-4M TYPE FUEL ASSEMBLIES

Usually, if the excess reactivity of the WWR-CM reactor for the next cycle of its operation is unsufficient, two FA with the greatest burnup of fuel are unloaded from the core. In the delivered cells of the core FA are reloaded from central cells (4-4,4-5, 5-4, 5-5), in which higher burnup is achieved. In the delivered cells fresh FA are loaded. The increase of the reactor excess reactivity after such reloading provides a possibility of its operation during 2 cycles with length 22 days.

By choice of cells of the core of the WWR-CM reactor for testing of the IRT-4M type FA the following reasons were allowed. In FA , arranged in central cells of the core, the power peaking factor in 1.3-1.4 times is less, than in peripheral cells. With burnup of fuel during testing the FA power will decrease. Accordingly the maximum density of a heat flux will be reduced. Therefore, the IRT-4M type FA at the first stage of testing should be located in central cells of the core. After achievement in them of fuel burnup 20-25% the reloading of the IRT-4M type FA in peripheral cells of the core will allow to compensate a decrease of a heat flux density at the second stage of testing.

The core configuration of the WWR-CM reactor with arranged in the core four experimental IRT-4M type FA is shown in Figure 4. As it is seen from Figure 4 the IRT-4M type FA were loaded in 4-4, 5-4, 4-5 and 5-5 cells.

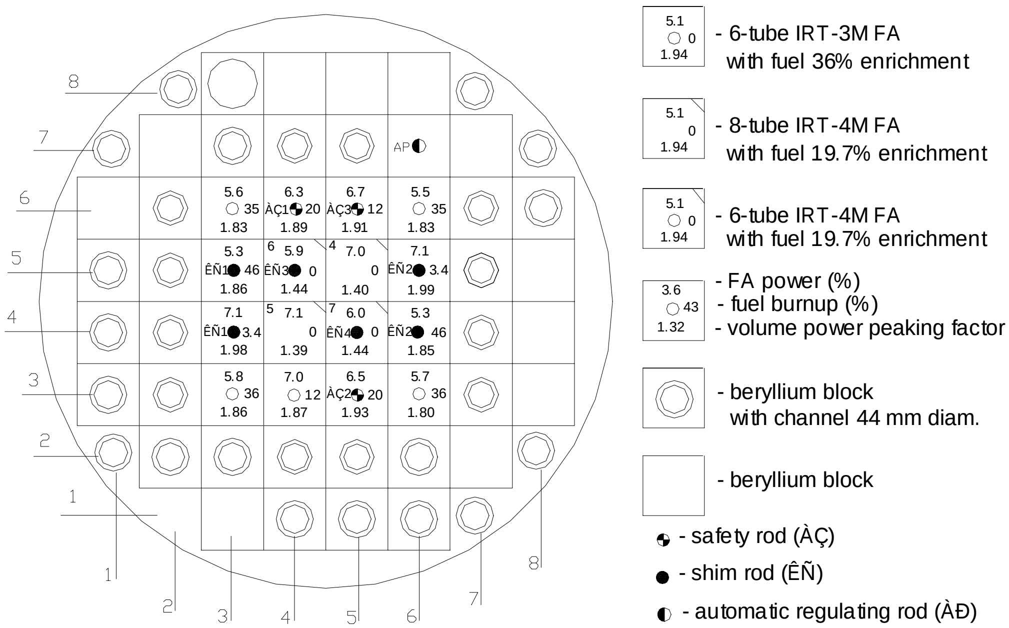
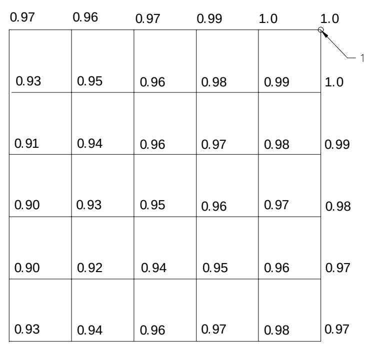


Fig. 4. The core configuration of the WWR-CM reactor with
the IRT-3M type (36%) and the IRT-4M type FA (19.7%)
(beginning of operating cycle, insertion of KC-3 and KC-4 – 24 cm)

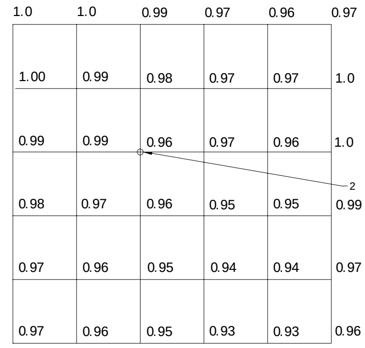
CONDITIONS OF THE IRT-4M TYPE FA TESTING

In Figure 4 the calculated values of FA powers, volume power peaking factors and values of average burnup of fuel in them are adduced. As it seen from Figure 4, the most power density is in the IRT-3M type FA in the 5-6 cell of the core. The power density distributions on section of the homogenized 4-4 cell with 8-tube FA of the IRT-4M type on 32.5 cm below of top of the core (maximum of power density) and on the height of the core in this FA (point 1) are shown in Figure 5. The power density distribution on section of the homogenized 4-5 cell with 6-tube FA of the IRT-4M type on 32.5 cm below of top of the core and on the height of the core in this FA (point 2) are shown in Figure 6.

The definition of the permissible level of reactor power was grounded on the analysis of a thermal regime of the FA with maximum power density in the core (5-6 cell). Thus with the help of the code ASTRA [15] the sector with maximum power density of this FA was considered. This code may be used for the analysis of steady conditions of cooling of fuel elements in FA of the IRT, WWR-M, WWR-TS and MR types prior to the beginning boiling.



section below the core top
on 32.5 cm (K_S=1.04)



section below the core top
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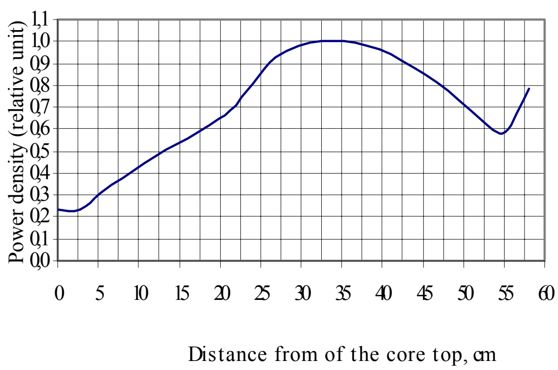
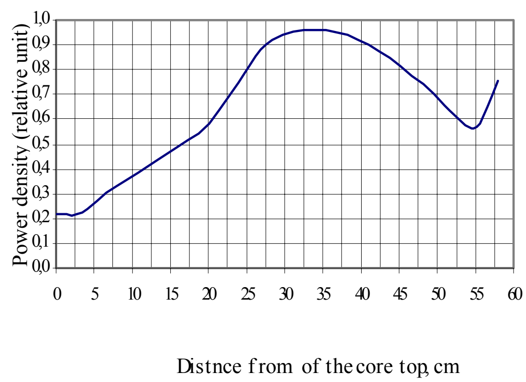


distribution through point 1
of horizontal section (K_Z=1.44)

Figure 5. Section and axial power density distribution in 4-4 cell with 8-tube the IRT-4M type FA (insertion of КС-3 и КС-4 – 24 см).



distribution through point 2
of horizontal section (K_Z=1.48)

Figure 6. Section and axial power density distribution in 4-5 cell with 6-tube the IRT-4M type FA (insertion of КС-3 и КС-4 – 24 см).

It considers sector carved from the hot party of assembly. In this sector 11 sections are considered sequentially – from inlet up to outlet of coolant (height of the core is divided into 10 intervals). In each section for each FE temperatures of outside and internal surfaces of the FE, temperatures between the meat and claddings, maximum temperature of the meat, and also heat fluxes from outside and internal surfaces of a FE are determined. Calculations are grounded on the solution of heat conduction equations for 3 cylinders: the meat and two claddings. Besides in each point temperature of beginning of surface boiling on Forster-Greif correlation [16] is calculated. The code allows to determine, whether has a place surface boiling or to receive a margin up to it.

In the issue of calculations with the help of the code ASTRA it was determined, that at a pressure drop on the core of 4.0 m water column (m.w.c.) and water temperature at core inlet of 45°C, supposing a margin before surface boiling in the FA with maximum power density equal 1.4 on temperature or 1.53 on power, maximum specific power density in the meat of fuel elements can reach $3.6 \cdot 10^6$ kW/m^3. It corresponds to reactor power 9.7 MW. For this value of nominal power with the help of the code ASTRA the values of maximum heat fluxes, maximum temperatures of fuel elements and margins before surface boiling both for the FA with maximum power density in the core, and for tested the IRT-4M type FA in 4-4 and 4-5 cells were calculated. The regimes of FA in 5-5 and 5-4 cells differ from regimes in 4-4 and 4-5 cells a little. Results of calculations are presented in table 2.

The calculated excess reactivity at the beginning of the first operating cycle of the WWR-CM reactor with a loading of the core with four the IRT-4M type FA is 6.1 % Δk/k. The values of the reactivity worth of the control and protection system (CPS) rods in this loading of the core are presented in the table 3.

Table 2. Parameters of a thermal regime FA in 4-4, 4-5 and 5-6 cells

Parameter	4-4 cell IRT-4M	4-5 cell IRT-4M	5-6 cell IRT-4M
FA power, kW	690	580	690
Water temperature at core inlet, °C	45	45	45
Pressure drop on the core, m.w.c.	4	4	4
Water velocity in 1-st gap of FA, m/s	3,04	3,04	3,21
Max. specific power density in the meat of FE $\cdot 10^{-6}$, kW/m^3	1,58	1,57	3,6
Max. heat flux density, kW/m^2	570	565	982
Max. temperature of a FE cladding, °C	85	85	101
Margin before surface boiling: -on temperature -on power	 1,87 2,18	 1,90 2,23	 1,40 1,53

Table 3. Reactivity worth of control and protection system rods of the WWR-CM reactor (Figure 4)

CPS rods	Arrangement in the core (cell)	Reactivity worth of rods (% Δk/k)
Safety rods:		
А3-1	6-4	1,42
А3-2	3-5	1,47
А3-3	6-5	1.45
А3-1 и А3-2	6-4, 3-5	3,1
Shim rods:		
КС-1	5-3, 4-3	2,8
КС-2	5-6, 4-6	2,8
КС-1 и КС-2	5-3, 4-3, 5-6, 4-6	6
КС-3	5-4	2,4
КС-4	4-5	2,4
КС-3 и КС-4	4-5, 5-4	4,7
Automatic regulating rod - AP	7-6	0,4

As it is seen from the table 3, the total reactivity worth of all KC and AP rods is 11.1 % Δk/k. Subcriticality of the reactor at the cocked safety rods (A3-1, A3-2 and A3-3) and all inserted in the core shim and AP rods not less 5 % Δk/k, though for good safety in case of possible error of staff at reloading of the core subcriticality not less 4% Δk/k is sufficient. This implies, that the reactor excess reactivity at the beginning of operating cycle should not exceed 7 % Δk/k. As it is seen from the table 3, the reactivity worth of two safety (A3-1 and A3-2) rods at their simultaneous inserting is 3.1 % Δk/k. At inadvertent withdrawal of any shim rod from the reactor being in a critical state, it will be trip at actuation 2 of 3 safety rods. Therefore, shutdown margins are sufficient.

CONCLUSION

In February, 1999 the conversion of the WWR-CM reactor on use of fuel of 36% enrichment was finished. Since July, 1999 the reactor operates with the compact loading of the core. The testing of the IRT-4M type FA with fuel enriched up to 19.7% will be begun in October, 2000. In the issue of performed neutronic and thermal-hydraulic calculations conditions at which the limits of safety operation of the reactor in the testing period of IRT-4M type FA will not be violated were determined.

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